INDUSTRIAL HYGIENE SECTION

This Industrial Hygiene Section is published to promote sound thought upon and concerning industrial hygiene. To that end it will contain articles, discussions, news items, reports, digests, and other presentations, together with editorial comments. The editorial policy is to encourage frank discussion. On this basis contributions are invited.

Industrial Medicine

Reg. U. S. Pat. Off.

The Editorial Committee will exercise its best judgment in selecting for publication the material which presents most exactly the factors affecting industrial health and developments for control of potentially injurious exposures. The editors may not concur in opinions expressed by the authors but will endeavor to assure authenticity of fact.

The Science, the Law and the Economics of Industrial Health

Volume 1 **OCTOBER, 1940** **Section 4**

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NATIONAL CONFERENCE 72
of Governmental Industrial Hygienists

OFFICIAL PUBLICATION of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION, WARREN A. COOK, Chicago, Ill., *President;* DONALD E. CUMMINGS, Denver, Colo., *President-Elect;* GORDON C. HARROLD, Detroit, Mich., *Secretary;* THEODORE HATCH, Philadelphia, Pa., *Treasurer.*

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Toxic Logic

TOSS the dust counters into a closet, lock the door and lose the key." "Dust is present, therefore a hazard exists." "This man has worked here the last 40 years without a sick day in his life: the place must be safe." "Carbon tetrachloride is less toxic than gasoline." "Gasoline is less toxic than carbon tetrachloride." "Air analyses don't mean a thing—the conditions change every day." "Toxic limits are valueless—they are all based on animals."

These and many another loose statement have been made and repeated on every side. The closer to the truth the statement is—without actually hitting the bull's eye—the more misleading the impression is apt to be. A general assertion about a scientific fact can often appear logical, even though it is essentially erroneous, by presenting only a portion of the whole situation. By the application of sound common sense to the use of toxic limits for the interpretation of air analyses, the industrial hygienist can utilize a valuable tool for the more effective and more economic control of occupational disease exposures.

A well-rounded presentation of the value of toxic limits, their practical purpose and the limitations of their use has been prepared for this issue by one of the world's most eminent industrial hygienists. His views are based on a wealth of experience in the field and an extensive knowledge of the literature. He is in excellent position to evaluate the reliability of toxic limits which have so far been published, as most of the actual experimental work has been done on them during the period of his active participation in industrial hygiene. Where the toxic limits of a number of organic solvents were determined on the basis of several hours' experiment on a small number of guinea pigs during the first decade of the century, he visualizes the results, not as figures on a published table to be blindly accepted, but as a group of experiments, the findings of which were published in detail as current literature earlier in his career.

The fallacy of the statement that "carbon tetrachloride is more toxic than gasoline" is that this does not apply to prolonged exposure but was based on brief animal experiment. To be sure, the literature states that only 2.2% of gasoline vapor in air will cause death whereas 4.8% of carbon tetrachloride is required to produce this result, but these findings are based on the concentration which kills a cat in 30 minutes. Where there is prolonged exposure, such as is contemplated in industrial occupation, it has been shown that carbon tetrachloride concentrations should be kept appreciably below those considered safe for gasoline vapor.

DR. TELEKY'S observations are the results of his own experiences and may not represent exactly the views of all our readers whose contact with the occupational disease situation may be from a different angle. The point of view of those who approach industrial hygiene in its various phases will be welcomed in connection with the conclusions expressed in DR. TELEKY'S paper.

A real endeavor should be made to utilize this tool further. The difficulty of not having data on exposures over long periods of a worker's employment, referred to by DR. TELEKY, should be provided for ahead of time by keeping on record average and representative exposures at potentially hazardous occupations from month to month or year to year depending on the nature of the operation.

An increasing number of industrial concerns and those engaged in mining are obtaining and collating just such data. Not only are these data of value in checking exposures, but they will also afford more exact and reliable information on which to base toxic limits.

The development of methods for the quick and easy determination of injurious materials in air is a long step in the right direction. The caution referred to by DR. TELEKY is to be observed, but it is only by use of methods which short-cut laborious laboratory procedures that we can hope for the mass of data required for positive conclusions.

Appreciate the value of toxic limits but, in making use of them, do not fail to observe their limitations.

We commend DR. TELEKY'S paper to your critical attention with the thought that for the full utilization of the toxic limit, one must apply the logic of practical common sense.

Economy in the Design of Exhaust Systems

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THE cost of controlling the health hazards associated with manufacturing processes may properly be regarded as a basic part of the production cost and is generally accepted as such today. This is in contrast to an earlier view that such costs represented an unnecessary addition to plant overhead. Too frequently, control equipment was installed in the past simply to satisfy some regulatory body and the main criterion was cheapness, without regard to efficiency. Little attention was paid to the essential engineering details of design and, as a consequence, money was wasted without getting the desired results. In general, the low initial cost was found to be offset by high operating cost due to excessive power consumption which made the equipment too costly to operate. The application of sound engineering principles to the design of control equipment however has demonstrated that good results can be obtained and, at the same time, that relatively great savings can be effected in the installation and operating costs. It is the purpose of the present paper to discuss in particular economy in the design of exhaust ventilating systems but the value of other more fundamental control measures must not be overlooked. For example, the substitution of a non-toxic substance for hazardous material or changing the process so as to reduce the rate of dispersion of the offending substance or the use of mechanized processes in place of manual operations are all basic improvements which may eliminate the need for ventilation or, at least, reduce the work which the ventilating system is required to do. The extent to which such changes can be made will depend upon the cost as compared with the savings effected. In certain cases where the hazard is a serious one, the substitution of a non-toxic material may be justified in spite of the higher direct cost.

The cost of operating an exhaust system includes the carrying charges on the initial investment, the depreciation and maintenance charges, the power cost and the extra heating expense imposed by the increased ventilation. In some cases there will be an additional labor charge because of the interference with production by the ventilating apparatus. Much can be done to reduce the costs of maintenance, power and heat through proper design and construction of the exhaust system. In many cases these savings can be effected without materially increasing the initial cost of the system and such savings therefore represent clear gain. In others, however, operating costs can be reduced only by increasing the initial expenditure for the control equipment and the most economical system must be determined by balancing increased carrying charges against savings. It is not the purpose of the present paper to analyze actual costs but rather to consider a number of

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good engineering practices, the application of which will reduce the cost of operating exhaust systems.

Power Consumption

THE power consumed by an exhaust system is determined by the product of the rate of air flow and the overall resistance of the system and is further influenced by the efficiency of the fan, thus

$$BHP = \frac{Qh}{6350\ E_{fan}}$$

Where BHP=brake horsepower
Q=rate of air flow, cfm
h=overall static resistance, ins.w.g.
E_{fan}=static efficiency of fan

Anything that can be done to reduce Q or h or increase E_{fan} reduces the power consumption. In general, the horsepower required is not great for a single system and, since the overall resistance does not exceed a few inches of water, a quarter of an inch of extra resistance here or there or the use of a few hundred cfm excess air flow is not regarded as serious. Relatively, however, these small extra values may be of great importance and proper attention to details will result in a reduction in power consumption of 25% or even more, which for a large establishment, becomes a major saving. In the small plant it is of greater relative importance although as an absolute value it will not be striking. For industry as a whole, it becomes of very great consequence. In New York State, for example, approximately 10 million cfm of exhaust ventilation was installed in 1939, requiring nearly 10,000 H.P. An average saving of 25% would reduce the power cost many thousands of dollars.

Design Requirements for Minimum Rate of Air Flow

THE minimum value of Q for a particular exhaust system equals the sum of the rates of air flow required for the several hoods. A fan capacity in excess of this must be provided, however, to make up for the lack of balance in the system which requires that the rate of air flow through hoods near the fan be increased above the minimum in order to maintain the necessary flow through the remote hoods. In a poorly constructed exhaust system additional fan capacity must also be provided to counteract the leakage at pipe joints.

Thus, the design requirements for minimum rate of air flow are:

1. High hood efficiency (minimum rate of air flow per hood)
2. A balanced system
3. Tight construction

In spite of the fact that empirical methods are generally employed in hood design it is possible to consider hood performance requirements from a fundamental standpoint and from this to develop many useful ideas, the application of which lead to improved design and reduced air flow requirements.

The function of an exhaust hood is to create in the zone of generation or release of the contaminant air velocities toward the exhaust opening of sufficient magnitude to overcome the forces tending to disperse the substance into the atmosphere and thus to draw it into the exhaust system. It follows that the hood velocity requirement will be decreased by any action which reduces the magnitude of the dispersive forces.

With respect to the forces of dispersion, I have pointed out elsewhere[1] that dynamic dispersion of dusts, that is, dispersion by virtue of the kinetic energy of the dust particles themselves, is not of consequence except in the case of relatively large particles ($> 20\mu$) and that microscopic particles ($<10\mu$) are scattered only by virtue of the movement of the air in which they are suspended.

Thus, the control of fine dust is not a matter of removing the dust itself from the air but rather of collecting the *dust-laden air*. This is also the case with vapors and gases. Hence, it is the air movement in the zone of generation of the contaminant, created by the process or otherwise, which must be overcome by the exhaust hood.

There are many sources of disturbing air motion which can be attacked directly with beneficial results. These have been summarized elsewhere[2] and only a few examples will be cited here to illustrate their importance in hood design.

1. Air is displaced when crushed rock falls through a chute into a container or onto a belt, the air movement taking place in the direction of flow of the material. The amount of air displaced varies with the distance of fall, particle size of the rock and the rate of flow of the material, and also depends upon the resistance to air flow imposed by the system. In one case, actual measurements showed that the rate of air displacement amounted to fifty times the volumetric rate of flow of rock with outward air velocities from the container being filled of the order of 300 fpm in one case and 1100 fpm in another.[3] The rate of air displacement can be cut down by reducing the area of openings through which air enters the system, by breaking up the fall of the rock or by keeping the lower part of chute full of rock. A surge chamber at the bottom of a chute just above a conveyor belt with a floating gate, as shown in Fig. 1, will practically eliminate the outward escape of air and reduce to a minimum the dispersion of dust.

2. Air motion is created by rotating and reciprocating machine members on the process itself or on nearby machinery. Proper shielding of such parts will reduce the rate of air displacement. A striking

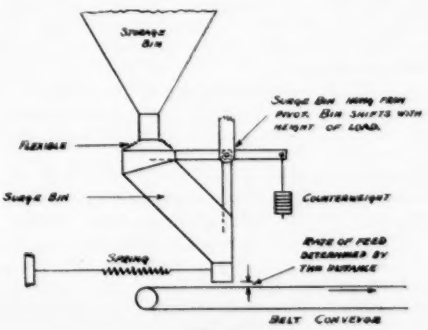

FIG. 1.
Dustless Ore Chute

example of this source of air motion was seen in a cable covering and impregnating machine. The rotating spool for applying the spiral cover was located adjacent to the hot asphalt impregnating tank and the strong fan action of the revolving wheel dissipated the asphalt fumes with considerable velocity. A shield between the two greatly reduced the hood velocity requirements.

Another example, familiar to all, is the common grinding wheel which actually blows air out of the exhaust hood in spite of the strong inward suction. A scalping vane, as shown in Fig. 2, was found to reduce the adverse fan action greatly, although its practical application to grinding wheels is doubtful, owing to the need for frequent adjustment as the wheel wears.

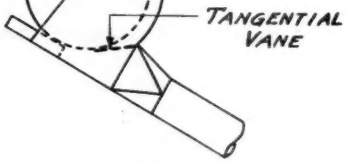

FIG. 2.
Scalping Vane to Improve Action of Gringing Wheel Hood

Convection currents set up by a hot process may increase the ventilation requirements. In a study of steam tank ventilation, for example, steam-laden air was found to escape out from under a canopy hood over the tank when the ventilating rate was under 800 cfm although the volume of steam generated was less than 50 cfm. Thus, a vertical flow of room air of some 15 times the rate of steam generation was created immediately around the tank. Suitable insulation of the tank would have reduced the strength of the convection currents greatly and with it the required ventilation rate.

3. Leaky compressed-air operated tools are frequent offenders and may create relatively great air velocities in the zone of dust generation. The leakage of air out around the shank of the pneumatic granite surfacing tool sets up a strong air blast onto the stone immediately adjacent to the cutting area and thus scatters the dust. A baffle disk on the shank of the tool eliminates this, or better, a series of vents around the chuck chamber itself directs the air away at a point well above the stone thus decreasing the velocity of dust dispersion.

4. The hood velocity required to overcome the dispersing force can be reduced in certain instances by increasing the distance over which the opposing velocity works (since work equals force times distance). Thus, spray booths should have sufficient depth to minimize the escape of spray materials due to rebound. Inspection openings in the walls of enclosures may be provided with side baffles to make a tunnel-like opening instead of a simple orifice, as shown in Fig. 3. Theoretically, if the distance over which the controlling velocity acts is doubled, the velocity itself may be reduced some 30% for equally effective control.

5. Uncontrolled drafts and convection currents in the work shop may produce needless dispersion of the contaminant. In a study of degreasing tanks[4] the need for eliminating such disturbing currents was clearly shown. In this connection, special care may be required in locating intakes for the entrance of make-up air into the room to minimize disturbance.

The foregoing examples are illustrative of the measures that can be taken to reduce the work to be done by exhaust hoods. The controlling velocity finally required is preferably determined by direct experimentation which yields a correlation between the rate of ventilation and the concentration of contaminant in the breathing zone. The expense involved in such studies is not great compared with the benefits derived therefrom and only by means of data thus collected can hood design be placed upon a fundamental basis. The volume of literature on this subject is increasing but much remains to be done by the various organizations concerned. It is especially recommended that the ventilation requirements of particular machines be investigated by the manufacturers themselves who will then be in a position to make definite recommendations to the purchaser.

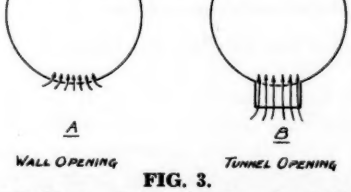

FIG. 3.
Tunnel Baffles on Inspection Opening to Increase Distance over which Velocity Acts

Hood Efficiency

THE rate of air flow through the exhaust hood required to develop the controlling velocity in the zone of generation or release of the contaminant depends upon the degree of enclosure around the process, or the closeness of the hood face to the area over which the contaminant is released and the opportunity for air to be drawn from areas other than the area of contamination. These factors combine to determine the aerodynamic efficiency of the hood which may be defined as the percentage ratio of the volume of air which does useful work to the total volume of air flowing into the hood. Although it is not possible to describe the air flow characteristics of complicated hoods, much useful information may be had from a study of the velocity contours of simple, unobstructed suction openings which have been described fully by DallaValle.[5]

Of greatest importance among the flow characteristics is the relation between velocity and center line distance from the hood face which may be defined approximately by the equation

$$V=\frac{0.1Q}{X^2+0.1A}$$

Where V=velocity at X distance out along center line, fpm
Q=rate of air flow through hood, cfm
X=distance out, feet
A=area of hood opening, sq.ft.

According to this equation, the velocity varies inversely with the square of the distance, which emphasizes the need for bringing the hood face as close as possible to the point of work. For example, Q may be quartered for a given controlling

velocity if the distance X to the point of generation of the contaminant is reduced by one-half.

A second factor to be noted is the relative unimportance of the velocity at the face of the hood which is found to have little influence upon the velocity any appreciable distance in front of the hood. It is the rate of air flow and not the face velocity which is important. From this, it may be said that for a given value of Q the face velocity should be made as low as possible by increasing A, the area of the hood opening. This has the advantage of establishing flat contours directly in front of the hood, and improves the hood efficiency by increasing the percentage of useful air flow.

The value of side baffles to reduce the air flow from ineffective areas back of the hood face has been demonstrated not only by studies of the velocity contours but also by direct experiment. Reductions in air flow of 25% or more have been effected through the proper use of baffles. Internal baffles, as illustrated in Fig. 4 are said to improve the flow pattern in the same way. They are also effective in decreasing the turbulence and eddying at the hood edge which may decrease hood efficiency[6] and are of value in controlling rebound from within the hood, as in a spray booth.[7]

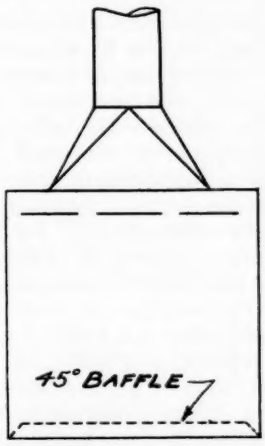

FIG. 4.
Internal Baffles on Spray Booth

These flow characteristics apply to the free-hanging hood. They are also applicable to lateral hoods and other semi-open conditions. In general, however, the objective in hood design is to provide an effective enclosure around the process and to such hoods the above laws do not apply. For high hood efficiency the enclosure must be as complete as possible and the controlling openings should be kept away from the major source of disturbance within the enclosure. In this way the unequal pressures that are built up will not create a high outward velocity through the openings.

The foregoing is not a complete summary of the design requirements for high hood efficiency, but it serves to direct attention to the fundamental approach through which savings may be effected.

Design of Exhaust Systems for Balanced Flow

IN A balanced exhaust system the rate of air flow through each hood equals or approximates the flow required by the hood design with no significant increase in the air flow rate for the hoods near the fan. In the common high-velocity system, however, the pipe sizes are simply calculated to give a uniform velocity (the so-called area-load method of design) throughout the system. The unequal distance of travel from the fan to the various hoods with a consequent difference in resistance leads to an unbalanced distribution of flow. The increase in the total rate of air flow required to insure the minimum flow in the remote hoods amounts in some cases to 30% or more. In order to improve the balance, an effort is made to provide a pipe layout symmetrical about the fan with not unusually long branch pipes and thus to equalize resistance. Blast gates may be used for a final adjustment although they cannot be depended upon permanently owing to wear and improper manipulation. It is a relatively simple matter to secure a balanced design in a system used for the removal of gases since the pipe velocities are unimportant and can be adjusted as required to compensate for the differences in resistance. In a dust exhaust system, on the other hand, the velocity cannot be reduced below that required for transporting the collected dust and all adjustments in pipe velocities must therefore be made in the range above this limit.

The following steps should be followed so far as possible to approximate a balanced design:

1. Provide for a symmetrical layout with minimum variation in the length of branch pipes and the shortest possible run of main pipe. Two or more systems may sometimes be employed profitably in place of one large system to give greater symmetry and balance.
2. Employ a lower velocity in the main exhaust pipe than in the branches. The effect of this is to make the branch pipe resistances relatively great as compared with the header resistance and thus to minimize the effect of the greater distance of travel to the remote hoods. It is common practice to increase the main pipe area 20% over the "area-load" for this reason and the same practice may be applied to long branch pipes.[8]
3. Increase the velocity in branch pipes near the fan by reducing branch pipe diameters and thus increase the resistance to compensate for the lesser distance of travel to the fan. This can be done by means of simple hydraulic equations of flow.[2] The effect is the same as that given by adjustable blast gates but the method is to be preferred owing to the fact that the adjustments are not subject to further manipulation and will not wear away.

The unequal resistance in the various parts of an exhaust system results primarily from the fact that high pipe velocities are required for transporting the collected material. The most effective design for balanced flow therefore is one that does not make use of pneumatic conveying of the collected material. No branch or main pipes are used and the dust falls by gravity into a low-velocity plenum chamber from which it is removed by a mechanical conveyor. Since the negative pressure is practically uniform throughout the chamber, the rate of flow through each hood is dependent only upon the size of the opening. This method of design has many other advantages[9] which justify its use in spite of the higher initial cost as compared with that of a conventional high-velocity system.

Design Requirements for Low Resistance

THE overall resistance of an exhaust system is the sum of the pipe friction and the losses at the entrance to hoods, in elbows, pipe junctions, transition pieces, through air-cleaning equipment, the terminal discharge and other parts of the system. The resistance set up by these several parts varies with the square of the air velocity and it follows, therefore, that the greatest saving in resistance is given by reducing the pipe velocity. Dropping from 4000 to 3000 fpm, for example, will lower the resistance approximately 50%. Vapors and gases are conveyed at any velocity and the optimum value is determined by striking the economic balance between the cost of the piping and other construction costs and power saving. Standard equations have been developed for this purpose.[10] In dust exhaust systems, greatest savings are effected by eliminating the need for pneumatic conveying.

The equipment has an overall resistance of approximately ⅜" as compared with ⅞" in a conventional system for the same work and the power consumption is only 3 HP whereas it was 22 HP in an earlier high-velocity system which it replaced.

Even in high-velocity systems much can be done to save power through more careful consideration of the transporting velocity requirements. It is common practice to use a value of 4000 fpm for all dusts without regard to particle size, specific gravity or loading and to make no distinction between vertical and horizontal conveying. Velocities of this magnitude and even higher are required for certain materials but others are conveyed successfully at much lower speeds. Laboratory tests indicate that dried stone dust of the size encountered in industry can be moved at 2000 fpm and velocities of this magnitude are known to give satisfactory performance in several industrial installations. On the other hand, laboratory and field experience indicate that for wet material the velocity must be increased greatly. Above a certain moisture content there is no practical velocity that will prevent settlement. Fine wood dust, as generated in a cabinet shop, is conveyed successfully at 2000 fpm whereas heavy wet wood cuttings require a velocity of 4000 fpm or more. It is not my intention to recommend the general use of lower velocities than are now employed and even required by codes but simply to point out that it can be done safely in many instances with marked savings in power. There is need for a critical study of past experience in this connection and a more basic evaluation of the problem in the interest of economy and good engineering practice.

The design of piping and fittings for low resistance follows well-known lines. Hood losses are minimized by providing stream-line connections to the branch pipes. An increase in the hood coefficient from 0.7 to 0.95, which is wholly practical in many instances, decreases the entrance loss from 1.0 VP to 0.11 VP, an improvement of 90%. Elbows are constructed of five or more pieces or even stamped out to form a continuous curve and are given a centerline radius of 1.5 to 2.0 diameters, in order to minimize the elbow resistance. Junctions of branch with main pipes should be made at a gradual angle and preferably in streamline form. The junction loss for an angle of 15° is only 40% of the loss for an angle of 45°. Enlargement sections must be tapered rather than abrupt and for best results should have an included angle of 7°. Entrance and outlet pipes to filter houses should be provided with tapered transition pieces rather than abrupt connections. This reduces the losses at these points approximately 50%.

A badly designed weather cap introduces an unnecessary resistance which is greatly reduced through proper design. The use of a discharge chimney is recommended to recover part of the discharge velocity pressure. A saving of ½" or more, representing, in some cases, 10% of the overall resistance of the system, can be affected by this means alone.

The air-cleaning equipment accounts for a major portion of the system resistance and its design and capacity must therefore receive careful consideration. In the case of cyclone collectors, many special designs have been developed which offer low resistance but one finds frequently that dust collecting efficiency has been sacrificed in order to save power. This must be kept in mind when selecting a collector of the cyclone type. For the common type, the optimum capacity is obtained with an inlet velocity of 4000 fpm. For capacities above this value the resistance is greatly increased without improving the efficiency while the saving in resistance at lower capacities is offset by reduced efficiency. In the case of cloth filter collectors, the resistance is directly related to the ratio of capacity to cloth area and the latter must be carefully determined for each installation if high resistance is to be avoided. Mathematically, the resistance varies with the square of the filtering velocity and directly with the loading and resistance coefficient of the dust[11] according to the following equation:

$$h = \frac{rLtV^2}{7000}$$

Where h = increase in filter resistance, ins., w.g.
r = coefficient of resistance of the dust, which varies markedly with particle size and porosity
L = dust loading, grains per cu.ft.
t = time of operation since last cleaning, minutes

This equation has limited application to filter design at the present time owing to lack of data pertaining to L and r. Its greater use is to be recommended, however, in the interest of power saving on the one hand and optimum filter cost on the other as demonstrated by Hemeon.[12]

The manufacturers of air-cleaning equipment, through their experience, are prepared to make specific recommendations with respect to the type and size of equipment required for each installation.

Fan Selection

THE selection of the most efficient fan with respect to type, size and speed depends upon the capacity and static pressure to be developed

and also upon the nature of the material to be handled. The leading fan manufacturers have developed efficient fans for a great variety of duties and are prepared to make specific recommendations for every installation. Full use of their service will result in significant power savings.

Summary

THE cost of controlling atmospheric contaminants released by manufacturing processes by means of exhaust ventilation includes the carrying charges on the initial investment, maintenance costs, the cost of power and extra heat, and in some cases, an extra labor charge resulting from interference with production by the control equipment. The most economical design of an exhaust system is one which balances the carrying charges against the operating costs to give a minimum value. The present paper considers the various design factors which together determine the power consumption and indicates a number of measures which can be taken to reduce the power charge. These are summarized as follows:

1. Reduce the magnitude of the forces of dispersion of the contaminant, thus decreasing the work to be done by the ventilating system.
2. Provide exhaust hoods of the highest aerodynamic efficiency.
3. Lay out the exhaust piping to give a balanced system.
4. Employ the lowest possible *safe* transporting velocity in the pipes or better, provide means other than pneumatic conveying for the removal of the collected matter.
5. Design hood entrances, elbows, junctions, enlargement sections and other pipe details for minimum resistance.
6. Select air-cleaning equipment of sufficient capacity to insure an economical resistance.

Attention to these and other details will reduce power costs 25% and even more in many cases and will insure longer life and lower maintenance costs. In certain cases these savings will represent clear gain. In others they will more than offset the increased initial cost. Their application requires the use of more fundamental engineering concepts however than are now applied to the design of exhaust systems generally.

References:

1. Hatch, Theodore: Design of Exhaust Hoods for Dust-Control Systems, *J. Ind. Hyg. & Tox.* 18, 595, 1936.
2. Drinker, P., and Hatch, T.: Industrial Dust, McGraw-Hill Book Co. New York, 1936.
3. Pring, R.: Dust Control in Large-Scale Ore Concentration Plants. Amer. Min. Inst., to be published.
4. Harris, W. B. *et al*: Safe Operation of Degreasing Tanks using Trichlorethylene *Am. J.P.H.*, 29, 603, 1939.
5. DallaValle, J. N.: Principles of Exhaust Hood Design, U.S.P.H.S. publication, 1939.
6. Yaglou, C. P. *et al*: Ventilation of Wire Impregnating Tanks Using Chlorinated Hydrocarbons. *J. Ind. Hyg. & Tox.*, 20, 401, 1938.
7. Hatch, T., and Northrup, R. B.: Exhaust Booth Designed to Insure Health and Safety in Spray Painting, *N.Y.Ind. Bull.*, 18, Nos. 7-8-9, 1939.
8. Hatch T., and Northrup, R. B.: Dust Control in Woodworking Plants by Exhaust Ventilation, *Heat. and Vent.*, Feb., 1940.
9. Hatch, T.: Low-velocity Dust Exhaust Systems Reduce Operating Costs—to be published.
10. Madison, R. D.: Fan Engineering, Buffalo Forge Co., Buffalo, 1938.
11. Williams, C. E., *et al*: Determination of Cloth Area for Industrial Air Filters, *Jour. Section, Heating, Piping and Air Cond.*, April, 1940.
12. Hemeon, W. C. L.: Personal Communication, material to be published.

Report of Industrial Hygiene Session

—National Battery Manufacturers Association—

Reviewed by
Eugene L. Walsh, M.D.

THIS privately printed brochure,[1] which has been previously announced,[2] contains in its first 78 pages the individual papers of the contributors. A supplement of 15 pages presents a verbatim report of the minutes of the Special Medical and Engineering Section.

Each author covers certain specific phases of the lead hazard in the storage battery plant. Obviously this method produces some repetition which is not undesirable, but rather serves to emphasize the need for coordination in terminology and methods in the various laboratory procedures in use today.

The assembled papers cover quite completely the industrial hygiene aspects of the lead problem in one industry. The engineering and medical problems are related in a report of a United States Public Health Service survey of the storage battery industry. The problems arising in the smaller plants are given in other papers. Safety problems receive due consideration and protective devices are very thoroughly considered, both with respect to the individual worker's protection and engineering protective devices for the manufacturing process. The medical and chemical laboratory aids used by the industrial hygienist in the diagnosis and control of lead hazards and intoxications is critically discussed by one capable authority. This topic receives the attention of others, also.

In the second section the organizers of this symposium have attempted, by the informal round table discussion method, to clarify a few of the controversial problems presented in Part I. In general this has been well done and in detail covers some of the more practical phases. Among the subjects discussed are the following: Methods of sampling air for analysis; limits of allowable lead concentrations; modes of dust abatement and worker protection; correlations and recommended practice for laboratory procedure, particularly with reference to stipple cells; the problem of acid fume exposure; and others.

The industrial lead problem is approached from the manufacturer, insurance carrier, personnel

1. Report of Industrial Hygiene Sessions of the 15th Annual Convention. Chicago, October 24-25, 1939. Released by National Battery Manufacturers Association, Akron, Ohio, 1940. $2.00 a copy.
2. Industrial Medicine, Industrial Hygiene Section, Vol 1, p. 42, July, 1940.

and industrial relations, compensation, employe and medical attitude in the various papers.

This volume is an authoritative practical epitome of the lead problem in the storage battery industry. It has been written by a well-chosen staff of men with wide practical experience. This review may be read with profit by the physician, engineer or executive interested in this industrial hazard.

Glycerol

—*Behavior in the Animal Organism*— (*A Review of the Literature*)

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GLYCEROL finds wide application in pharmaceutical preparations. In fact, according to Lesser and Murphy,[38] it is probably used more frequently in prescriptions than any other substance except water. Any toxic properties which it may possess are therefore of considerable importance.

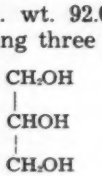
Data on the lethal and sublethal concentrations of glycerol obtained from the literature are summarized in the table.

There are only two cases on record in which glycerol has been known to produce poisoning; these were in children. The first child, two and a half years old, took 300 gm. orally; loss of consciousness followed, but the child recovered after its stomach was washed out. The second case was fatal, but unfortunately neither dose nor mode of administration is known.[31]

The ingestion of 30 cc. of glycerol three times daily over a period of 50 days by normal human subjects was found to be harmless,[29] but subcutaneous or intravenous injection of glycerol extracts may be followed by a local inflammatory reaction or by edema, while the injection of a 50% glycerol-broth culture of human tubercle bacilli in tuberculin-positive patients caused a skin reaction in many instances.[21,24]

Physical and Chemical Properties

GLYCEROL (mol. wt. 92.06) is the simplest alcohol containing three hydroxyl groups:



It is a viscous, colorless, odorless liquid with a neutral reaction and a sweetish taste; the specific gravity is 1.265 at 15°C.

It is miscible in all proportions with water, alcohol and chloroform but immiscible with ether, fats and oils.

Glycerol usually contains small amounts of water, because of its hygroscopic property, and when left exposed to the air will absorb more than half of its weight of moisture.

It boils at 290°C.

The Absorption of Glycerol

GLYCEROL is readily absorbed from the gastro-intestinal tract. Höber and Höber,[23] investigating the rate of absorption of equimolecular solutions of polyhydric alcohols from isolated loops of rat intestine, found that their absorption decreased with increase in their molecular weight. Approximately 73% of glycerol was absorbed as compared to 27% of erythritol and none of the mannitol. Johnson, Carlson and Johnson[29] found that 50% of the glycerol introduced into the intestine of anesthetized dogs, was absorbed during the first two to three hours. There was little absorption from the stomach.

Glycerol, like the hexoses, apparently unites with phosphates during its absorption from the intestinal tract. This is indicated by the increased content of acid-soluble organic phosphates in the mucosa of the intestine after oral administration of this compound (Laszt and Süllmann[35]).

A mixture of glycerol and phosphates, or even better, glycero-phosphate, administered together with glycocholic or taurocholic acids increases the rate and extent of absorption of a fatty acid such as oleic acid. On the basis of these observations Verzár and Laszt[83] concluded that the esterification of glycerol with phosphoric acid occurs in the mucous membrane.

Glycerol is absorbed rapidly if administered intraperitoneally, but slowly if given subcutaneously. The subcutaneous injection of small amounts usually presents no difficulties in animals, even though serious effects may be produced with larger doses. The intravenous injection of undiluted glycerol may result in occlusion of blood vessels.[10] Maignon and Grandclaude[47] reported the production of sclerosis of the veins in dogs by the injection of 3-5 cc. of pure glycerol.

The absorption of aqueous glycerol solutions from the blood stream starts immediately after injection.[78,37]

When applied to the unbroken skin, pure glycerol apparently is not appreciably absorbed.[10]

Acute Toxic Effects Induced by Glycerol

THE administration of glycerol to the horse, dog, cat, rabbit, rat and mouse in a single dose sufficient to cause death produced either restlessness or diminished activity, followed by an increased pulse rate, vomiting (in the horse and dog), occasional biting movements, a mild cyanosis, tremor, diuresis, some loss of equilibrium, severe clonic convulsions and death in coma.[31,40,69,58,29,68,55,36,10] Schübel[69] noted that the convulsions could be initiated by noise, an observation which we have made in the case of rabbits.[10]

Rabbits and rats show a marked inactivity, diuresis, loss of appetite and sometimes convulsions[10] in response to sublethal doses of glycerol. Kobert,[31] in 1906, called attention to the narcotic action of glycerol.

The Effect of Glycerol on Blood Pressure and Respiration

SCHUBEL[64] injected urethanized cats with doses of 1 cc/kg and noted an immediate drop in blood pressure of from 30 to 40 mm. The pressure rose again quickly, however, passing the normal, and remained elevated (40 mm. above normal) for 20 minutes. He attributed this temporary increase in pressure to an hydremic plethora, the water of the tissues being taken up by the circulation. Johnson, Carlson and Johnson[29] noted a transient fall in the arterial pressure, even after a small intravenous dose of glycerol. In addition to this, Trabucchi[78] observed an increased rate and magnitude of respiration in rabbits, which persisted after vagotomy. In our experiments on rabbits lethal oral doses produced a slowly failing circulation, lethal intraperitoneal injections produced a marked stimulation of respiration followed by a sudden drop of arterial blood pressure. Death was due to the combined effects of failing circulation and respiration.[10]

The Effect on Muscle, Intestine, Uterus and Blood Vessels

FROG muscles injected with or suspended in very dilute aqueous solutions of glycerol show a greatly increased and prolonged state of irritability, according to the observations of Santesson[66] in 1903, and Verzá and Peter[82] in 1925. Reach[61] found that glycerol caused a relaxation of the sphincter of the gall-bladder, when applied to the upper part of the duodenum. Pal and Prasad[52] noted an increase in the force and amplitude of intestinal contractions. No change in bowel activity was observed by Johnson, Carlson and Johnson in rats and dogs but there was a slight tendency toward softer stools in the human beings who in-

TABLE
LETHAL AND SUBLETHAL CONCENTRATIONS OF GLYCEROL (AS TAKEN FROM THE LITERATURE)

Species	Mode of Administration	Dose	Fate	Investigator
Child 2½ yr.	oral	300 gm	loss of consciousness, with recovery (stomach was pumped out)	reported by Kobert[31]
Child	?	?	fatal	" " " "
10 men and 4 women	oral	30 cc 3 times daily	no harmful effects	Johnson, Carlson and Johnson[29]
Horse	subcutaneous	300 cc	died in 27 hr.	Plosz[58]
"	"	100 cc	slight fever	" "
Dog	"	8-10 gm/kg	died in 24 hr.	Dujardin-Beaumetz and Audige, cited by Arnschink[2]
"	"	14 gm/kg	died in 3-4 hr.	Dujardin-Beaumetz and Audige, cited by Arnschink[2]
"	oral	up to 7 gm/kg	no illness	Lewin, cited by Arnschnik[2]
"	"	" " 8 " "	" "	Tschirwinsky, cited by Arnschnik[2]
"	"	7-11 gm/kg	intest. disturbances, vomiting	Arnschink[2]
"	"	35 % glycerol in diet	no ill effects	Johnson, Carlson and Johnson[29]
Rabbit	cutaneous	12 doses of 4.5 cc/kg	no signs of illness	Deichmann[10]
"	intraperitoneal	7 cc/kg	smallest dose lethal	" "
"	Subcutaneous	10 cc/kg	" " "	" "
"	oral	14 cc/kg	" " "	" "
Rat	intraperitoneal	5-6 cc/kg	killed from 40-80 %	" "
"	subcutaneous	4-5 cc/kg	may be fatal	Schubel[69]
"	"	8 cc/kg	minimal lethal dose	Pfeiffer and Arnove[55]
"	"	15 to 16 cc/kg	killed from 60-70 %	Deichmann[10]
"	"	13 cc/kg	killed 80 % (starved for 3 days)	" "
"	oral	5.7-14.8 cc/kg	no ill effects (starved 24 hr.)	Johnson, Carlson and Johnson[29]
"	"	41 % glycerol in diet fed 40 wk.	no ill effects...	" " " " "
"	"	21-23 cc/kg	killed from 40-60 %	Deichmann[10]
Mouse	subcutaneous	9-11 cc/kg	fatal to 80 %	Leake and Corbitt[36]

gested 90 cc. daily. Kobert[31] and Lewin[40] reported loose stools in human beings who ingested large amounts of glycerol. Schübel[69] found that glycerol had little or no effect upon the intestine and the uterus. This investigator also reported that a concentration of glycerol from 1:10 to 1:1000 had no effect upon the blood vessels and that it took a concentration of from 1:50 to 1:100 to exert a depressant action upon the isolated frog heart.

Effect of Glycerol on the Blood Picture

SIMON[72] observed anemia in rabbits injected intravenously. There was however a marked increase in the total leucocyte count count, a slight decrease in lymphocytes and a marked increase in the polymorphonuclear neutrophils. The injection of glycerol into the heart of rabbits was followed, in our experiments,[10] by a decrease in erythrocytes and in the hemoglobin concentration and an increase in leucocytes, findings which confirm Simon's observations.

Sugimoto[75] reported anemia in rabbits treated subcutaneously with 3 cc/kg. A pronounced decrease in erythrocytes and leucocytes and in the hemoglobin concentration was noted in our experimental animals[10] after the subcutaneous injection of lethal doses of glycerol. The repeated subcutaneous injection of sublethal doses had the same effect on the erythrocytes and the hemoglobin while the number of leucocytes fluctuated within a wide range.

Tompkins[77] obtained a well defined increase in the leucocytes of guinea pigs after intraperitoneal administration of glycerol in doses as great as those involved in injections of old tuberculin. There was a slight increase in monocytes and a marked increase in neutrophils. We[10] noted no significant change in the number of erythrocytes or in the hemoglobin concentration of the blood of rabbits during the first four to six hours after intraperitoneal injections of sublethal doses, but the number of leucocytes was increased. Twenty-four hours after the injection the hemoglobin was found to be below the pre-experimental level in some instances, while the leucocytes had returned to normal limits.

Johnson and Carlson[28] noted no change in the blood picture of human subjects who ingested 90 cc. of glycerol daily for 50 days. These results are in accord with our findings in rabbits to which glycerol was administered orally.[10]

Repeated applications of glycerol to the skin of rabbits induced no illness and no changes in the blood.[10]

Hemoglobinuria Due to Glycerol

LUCHSINGER[43] appears to have been the first to observe the production of hemoglobinuria in rabbits by subcutaneous injection of glycerol. His observations have been confirmed in the case of rabbits, dogs and rats, by Ustimowitsch,[80] by Miura,[49] by Johnson and Carlson,[28] by Simon,[70] by Sugimoto,[75] and by Deichmann.[10]

In 1937, Pfeiffer and Arnove[55] observed that 0.75 cc/kg was the smallest subcutaneous dose capable of producing hemoglobinuria in rats. They also found that the preliminary administration of ascorbic acid raised the parenteral dosage necessary to produce hemoglobinuria by 100% or more. The occasional production of hemolgobinuria in rabbits, but not in rats, by intraperitoneal administration was noted by Simon[70] and has been observed in our experiments.[10]

According to Simon,[72] the intravenous administration of glycerol to rabbits never produces hemoglobinuria, but our observations were not in complete accord with this statement. Of five rabbits, each of which received two injections of from 2 to 3 cc/kg into the heart, one showed a marked hemoglobinuria.[10] Kobert[31] reported the production of hemolysis by intravenous injections.

Miura[49] administered glycerol orally in sublethal concentrations to dogs and rabbits and observed no hemoglobinuria. These findings were confirmed by Johnson and Carlson[28] in the case of dogs, rats and rabbits, and by our observations on rabbits and rats.[10] Johnson, Carlson and Johnson[29] also failed to obtain hemoglobinuria in 14 human subjects who ingested 90 cc. of glycerol daily for 50 days.

Hemolysis Produced in Vitro by Gylcerol

AQUEOUS solutions of glycerol will hemolyze erythrocytes; this hemolysis appears to be more pronounced when the concentration of glycerol is low.

Jacobs, Glassman and Parpart[27] studied the rate of hemolysis by adding one part of blood to 500 parts of an isosmotic glycerol solution. They observed rapid hemolysis of the erythrocytes in man, rat, mouse, rabbit and guinea pig, and found that this could be retarded by increasing the CO_2 tension of the solution. The erythrocytes of the ox, sheep, horse, pig, dog and cat hemolyzed slowly, but this hemolysis could not be retarded by increasing the CO_2. They write: "By saturating an isosmotic gylcerol solution with alveolar air (though much lower tensions of CO_2 are effective) the time of hemolysis of red blood cells by glycerol may be prolonged to 50 or more times their normal values, this effect being readily reversible by the removal of CO_2 or by addition of $NaHCO_3$ to the solution. A striking inhibition of the effect of glycerol on the erythrocytes may be produced by traces of copper or of copper salts in the water (Jacobs and Carson[26]). This effect, which is not obtained with the blood of some animals, (cat, dog, sheep, ox), and only slightly with that of others, (rabbit, guinea pig), may be so pronounced with the blood of man, for example, that the use of water distilled in an ordinary copper still may change the time of hemolysis in 0.3 M glycerol at 20°C. from 30 seconds to 15 minutes or more. Equally striking effects may be obtained with the blood of the rat."

Schübel[69] studied washed erythrocytes placed in saline solutions and in water containing varying concentrations of glycerol. He noted no hemolysis in saline solutions containing up to 40% glycerol, while in 50% solutions hemolysis began after from 16 to 20 hours. As for aqueous solutions, a 20% solution of glycerol caused hemolysis

after approximately 15 minutes, a 30% solution after 30 minutes, and a 40-50% solution after 90 minutes. Calculated on an osmotic basis, a 2.55% solution of glycerol should be equivalent to a 0.9% solution of sodium chloride; however, glycerol was not found capable of replacing NaCl in isotonic solutions.

The Effect of Glycerol on the Body Temperature

IN 1887 Plosz[58] and Arnschink[2] reported that glycerol caused an elevation of the body temperature, an observation that was confirmed by Schellenberg,[68] who gave his patients a mixture of iodoform and glycerol. Johnson, Carlson and Johnson[29] observed no increase in temperature in a series of dogs to which glycerol was administered. In our experiments[10] rats, injected subcutaneously, suffered a drop in body temperature in direct relation of the size of the dose, but reacted variably to intraperitoneal injections in that no change in temperature occurred in some instances while in others the temperatures were depressed or elevated. Rabbits injected subcutaneously, orally or intraperitoneally, either maintained a normal temperature or developed a distinct fever.[10]

The Diuretic Action of Glycerol

IN 1876 Ustimoetisch[80] noted a diuretic action exerted by glycerol in dogs and rabbits. He observed also that the volume of urine secreted was always much greater after oral administration than after subcutaneous injection of glycerol. Dux and Löw[15] reported that the injection of this compound into the muscle of the frog was followed by loss of water which in some cases amounted to as much as one-fifth of the normal weight of the muscle. Schübel[69] produced a tenfold diuresis by the intravenous injection of glycerol into urethanized cats. The relationship between the degree of the diuresis and the concentration of the glycerol was studied by Cugusi[9] in 1922. He found that an intravenous injection of 1.2% gm/kg glycerol in a normal NaCl solution produced a notable diuresis; doses of from 2 to 2.4 gm/kg brought about a pronounced diuresis, while doses ranging from 4 to 6 gm/kg caused an inhibition of urine formation. Johnson, Carlson and Johnson[29] noted this inhibition also, but only when the intravenous dose of glycerol produced a marked lowering of the blood pressure at the same time. These authors noted no diuresis nor change in specific gravity of the urine in men and women who ingested about 100 gm. daily for 50 days, but rats and dogs on a diet containing 41 and 35% glycerol secreted approximately five times as much urine as control animals. Three of the five subjects of Lewis and Corley[41] who received 59 gm. of glycerol showed no diuresis.

The observations indicate that diuresis occurs after a moderately large dose of glycerol, but ceases if the toxic effects of this compound get the upper hand.

The Effect of Glycerol on Enzymes

A DOSE of 10 gm. glycerol per kilogram of body weight introduced into the stomach and upper portion of the intestine of an etherized dog, in Burge's experiments,[3] caused a 50% increase in the catalase concentration in the blood of the liver and the portal and jugular veins.

According to Allesandrini,[1] glycerol has no injurious effect on amylase, while Di Frisco[12] reported that pancreatic juice heated in the presence of glycerol does not lose its activity completely. Farber and Wynne[16] in studying the breaking-down of caseinogen by pancreatic protease in vitro found that glycerol "inhibits the initial rate of hydrolysis."

In our experiments subcutaneous injection of lethal concentrations of glycerol into rabbits and rats caused pronounced edema and hemorrhage at and near the site of injection. Within from 20 to 40 minutes after an intraperitoneal injection of 2 cc. of glycerol into rats, we observed accumulation of fluid in the peritoneal cavity which in some rats amounted to 10 cc. The oral administration of this compound was usually followed by an acute irritation of the whole intestinal tract. Rigor mortis usually developed in from three to five minutes after death.[10]

The Formation of Glycose from Glycerol

CREMER'S investigations[8] offered the earliest evidence of the transformation of glycerol into dextrose, though Ustimowitsch[80] and Plosz[58] had previously reported the occurrence of a Cu-reducing substance in dog's urine after the ingestion of glycerol. Cremer found that about 40% of the glycerol ingested by a phlorhizinized dog was excreted in the urine as "extra glucose." Chambers and Deuel[6] repeated Cremer's experiments and confirmed his observations. In 1904 Lüthje[44] administered glycerol to pancreatectomized dogs and found that this resulted in glycosuria. Voegtlin, Thompson and Duns[84] administered 20% aqueous solutions of glycerol orally and intraperitoneally to fasting rabbits and produced extensive and prolonged hyperglycemia. McLean[46] obtained substantiating data. Koike[32] and Yagi[89] introduced glycerol intraperitoneally into rabbits and noted hyperglycemia and an increase of lactic acid in the blood. The lactic acid so produced remained at a higher level than that resulting from the injection of equivalent doses of galactose, maltose, glucose, fructose and mannose. The hyperglycemic response was not attributable to the mobilization of liver glycogen but to the formation of glucose from glycerol. The excreted sugar could not possibly have been formed from the small amount of protein ingested. Complete conversion of glycerol into glucose may occur but the individual response is variable, perhaps because of incomplete absorption of the compound.

According to Ferber and Rabinowitsch,[17] when glycerol was administered on an empty stomach to healthy persons and patients in amounts up to 100 grams (diluted with water to 250 cc.), it produced hyperglycemia, the degree of which was directly related to the disturbance of the carbohydrate metabolism. In advanced cases of diabetes glycerol produced glycosuria. Parnas and Wagner[23] reported that the feeding of glycerol was responsi-

ble for an increased blood sugar concentration in a girl of nine who was suffering from a liver tumor. These reports indicate definitely that glycerol is a precursor of sugar in the organism, even though Kneip[33] does not share this opinion.

The Formation of Glycogen From Glycerol

CATRON and Lewis,[5] in observations on fasting rats over periods up to six hours, found that the glycogen content of the liver increased progressively to an average maximum of 143 mg. glycogen per 100 gm. body weight, in response to the administration of glycerol by means of a stomach tube. The amounts of liver glycogen formed during the two- and three-hour periods were similar to those observed after the absorption of glucose. Lederer[37] confirmed these observations in 1936. He found that the ingestion of glycerol by a fasting rat as well as the intravenous injection of glycerol into rabbits and dogs increased the hepatic glycogen. Reid[63] slowly infused glycerol into the veins of anesthetized cats and observed that liver glycogen was formed. Reid also found that glycogen deposition or breakdown in starving cats was in direct proportion to the body temperature, when other factors were kept constant. At 37° c. there was practically no change, at 38° c. there was a constant slight decrease, while at 40° c. a rapid decrease in the liver glycogen occurred. By means of perfusion experiments Lederer[37] brought proof that even in vitro, rabbit and dog livers formed glycogen from glycerol and that none of this power was lost in the icterus produced by experimental phosphorus poisoning.

These reports fully confirm the early observations of Weiss,[87] of Luchsinger,[43] of Salomon,[65] and of Hammersten,[19] who observed an increase in the glycogen of the liver after the feeding of glycerol to chickens and rabbits. Investigators who failed to make these observations either worked with amounts of glycerol which were too small, or carried out experiments of too short duration.[56,13]

The Effect of Glycerol in Counteracting the Action of Insulin and the Formation of Acetone Bodies

GLYCEROL leads to the formation of glucose and glycogen and therefore counteracts the effect of insulin and exerts a preventive action on the formation of acetone bodies. Noble and Macleod[51] recognized the fact that if glycerol is to exert any curative action on insulin coma it must be administered in a promptly available form. Pure glycerol proved to have little effect. The intraperitoneal or intravenous injection of a 20% aqueous solution of glycerol by Voegtlin, Dunn and Thompson[85] quickly banished the coma and convulsions induced in rats by a lethal dose of insulin. Reeves and Hewitt[62] also noted that the administration of glycerol was of assistance in combating the phenomena of hypoglycemia induced by insulin. Trabucchi[78] injected glycerol in the form of a 30% solution into rabbits, using a dose of 5 gm/kg, and followed it immediately by an intramuscular injection of insulin. He noted that the glycerol disappeared more rapidly from the circulation blood of these animals than from that of non-insulinized rabbits. Decrease in the formation and excretion of acetone bodies in diabetics and normal fasting persons and animals following the ingestion of glycerol was reported by Hirschfeld in 1895,[22] by Satta in 1905,[67] by Lang in 1915,[34] and by Chambers and Deuel in 1925.[6]

The Protein-Sparing Action of Glycerol

LITTLE definite information is available regarding the possible protein-sparing action of ingested glycerol. Dubois and Combemale[14] studied the urea excretion before, during and after glycerol feeding; in their experiments the reduction in the excretion of urea was too small to warrant the assumption of a conservation of the proteins. Very similar results were obtained by Munk,[50] Lewin,[39] and Tschirwinsky,[79] Strack,[74] however, observed a definite protein-sparing action and Chambers and Deuel[6] found the protein-sparing activity of glycerol to be similar to that of the monosaccharides.

Glycerol apparently will exert a protein-sparing action only when it is administered in high but tolerable concentrations.

The Effect of Glycerol on the Respiratory Quotient

THE effect of glycerol on the respiratory quotient is controversial. McCann and Hannon[45] and Johnson, Carlson and Johnson[29] found no consistent response on the part of the respiratory quotient to the ingestion of from 40 to 100 gm of glycerol by diabetic patients or normal persons. On the other hand, Chambers and Deuel[6] found a reduction of the respiratory quotient in three phlorhizinized dogs, after the oral administration of 8.5 gm. of glycerol. They explain their results by saying: "The decrease in R.Q. from 0.703 to 0.678 after giving glycerol indicates that there was no general oxidation of the ingested glycerol, which has an R.Q. of 0.857, nor of the glucose into which it was converted. The reduction in the R.Q. from 0.703 to 0.678 may be accounted for as due to the oxidation of the 2 atoms of hydrogen liberated in the reaction: glycerol = ½ glucose."

Glycerol as a Substitute for Carbohydrates in the Diet

IN 1933, Johnson, Carlson and Johnson[29] kept rats for 40 weeks on a diet consisting of 20% starch, 41% glycerol, 18% casein, 10% butter, 5% yeast, 4% inorganic salt mixture and 2% agar. The animals grew as well as control animals given a diet containing 61% starch. Three dogs kept for 36 weeks on a diet containing 35% glycerol, 17% carbohydrates, 24.5% protein, 7% fat, 2.5% yeast and 14% bone meal also showed the same gain in weight as control dogs kept on a diet in which none of the carbohydrate was replaced by glycerol. By reducing the food intake of these dogs while following their weight changes these workers demonstrated that glycerol is not calorically equivalent to glucose when it makes up more than 35% of the diet. They also studied 10 men and four women ingested 30 cc. of 95% glycerol with orange juice three times daily after each meal for 50 days. These subjects developed some tendency

towards increase in body weight, and described such subjective effects as: "increased thirst occasionally (two subjects), and occasional sensation of warmth in the stomach after ingestion, especially in those instances when the glycerol was taken not with a meal but on an empty stomach (four subjects), and even a feeling of particular well being and exceptional freedom from colds (one subject). There were no reports of sleeplessness, talkativeness, or excitement." In 1929 Ferber and Rabinowitsch[17] gave oral doses of 100 gm. of glycerol in 250 to 300 cc. of water to 60 patients and noted little if any effect therefrom. No instance of gastro-intestinal disturbance occurred and only five complained of any discomfort, the latter consisting usually in a throbbing headache or dizziness, which these authors feel may well have been due to lack of food since the glycerol was taken on an empty stomach, 10 hours after the last meal. Flury and Zangger in 1928[18] stated that oral doses of 100 gm. of glycerol produced vomiting and headache in humans, but the more recent observations indicate that this holds true only in isolated cases. In 1937 Holck[25] confirmed the harmlessness of a diet containing 20% glycerol, on which rats were kept for 11 weeks. According to Delaunary and Accoyer's investigations,[11] reported in 1936, the normal rat is capable of assimilating a maximum of 0.4 gm. glycerol per 100 gm. body weight per day when the glycerol is mixed with the food.

The Effect of Glycerol on Uric Acid Excretion

ROSENFELD[61] and Quick[60] among others have called attention to an increased elimination of uric acid concretions and sediment after glycerol ingestion. Hansen and Kamm[20] offer the following explanation for the beneficial influence of glycerol on nephrolithiasis: by dissolving out the inorganic matrix of the uric-acid calculi, glycerol breaks them up into fine granules which settle out slowly and therefore remain suspended in a mixture of urine and glycerol instead of adhering to the wall of the bladder; in this free state they are easily voided with the urine. Johnson, Carlson and Johnson[29] found no significant change in the excretion of uric acid in their human subjects after the latter had ingested 90 cc. of glycerol daily for 50 days. Their subjects were healthy young people and consequently these findings would have little bearing on the question of the disintegration and elimination of pre-existing uric-acid calculi.

The Effect of Glycerol on Reproduction

THE normal reproduction of rats is not influenced by the substitution of glycerol for starch up to a point where the former comprises 41% of the total food intake. Pregnancies did not occur when rats received 61% of their diet in the form of glycerol.[29]

The Excretion of Glycerol

THE rate of the urinary excretion of glycerol depends upon a variety of factors such as the rate and mode of its introduction into the body, the composition of the diet, and the condiiton of the excretory organs. Even prior to 1887, the excretion of glycerol in the urine of human beings and dogs had been observed by Tschirwinsky,[79] Catillon,[4] and Arnschink.[2] According to Delaunay and Accoyer,[11] rats kept over a prolonged period on a diet including glycerol excrete all the glycerol absorbed in excess of 4 gm/kg.

Glycerol Absorption in Tuberculosis and Certain Other Pathological Conditions

THE filtrate employed in the treatment of tuberculosis is prepared from a concentrated glycerine-broth culture of human tubercle bacilli and is so titrated that it contains 50% glycerol and 1 mgm of tuberculin to each cubic centimeter of solution. At times glycerol bouillon gives a positive skin reaction when administered simultaneously with tuberculin to tuberculous guinea pigs. Heise and Brown[21] noted a positive reaction from glycerol bouillon and tuberculin in 4% of 443 cases of tuberculosis in adult human beings. Höchst[24] observed a positive reaction to injections of concentrated glycerol bouillon in 83 of 93 tuberculin-positive children and in 16 of 17 tuberculin-positive adults. Of 112 tuberculin-negative children, under the care of Keller and Dölter,[30] none reacted.

Long and Vorwald[42] administered glycerol, both orally and subcutaneously, to tuberculous rats over long periods. They observed an enhanced growth of tubercule bacilli in the lesions and a general increase in the severity of the disease. The majority of tuberculosus rats fed upon an excess of palmitic acid had smaller lesions than did tuberculous rats on a control diet.

Woolf[88] has reported good results in the treatment of hemorrhoids with a mixture of 40% glycerol, 20% phenol and 40% witch hazel, in conjunction with a 5% solution of phenol in almond oil.

Acording to Compton,[7] cancer cells of the epithelial type, in vitro, possess a high degree of resistance to the toxic action of pure glycerol.

Glycerol inhibits the action of staphylococcic toxin in causing necrosis of the skin of guinea pigs, an inhibition according to Smith[73] is specific for this toxin.

In 1931, Tashiro and Oliver[76] studied the possible antagonistic action of glycerol and cholesterol against bile salts. They found that neither of these compounds prevented erosion of the gastric muscosa, or death, in rabbits and guinea pigs injected intravenously and intraperitoneally with toxic doses of bile salts.

That glycerol prolonged the life of suprarenalectomized cats was demonstrated by Marine and Baumann[48] in 1927. Glucose appeared to be about equally effective in this respect.

Pathological Changes Caused by Glycerol

THE subcutaneous injection of glycerol into the horse or dog, produced edema at the site of injection, inflammation of the lungs and intestinal wall, and hyperemia of the liver and kidney.[58]

After injecting three rabbits subcutaneously with doses of glycerol sufficient to kill them in 24,

48 and 92 hours, respectively, Simon[70] found lesions mainly in the subcutaneous tissues, the liver and the kidney. At the site of the injection the glycerol had destroyed the framework of the connective tissue, the adjacent fascia had disintegrated into longitudinal fibrils and the muscle fibers had lost their cross-striations. The liver showed an increase in connective tissue, atrophy of the hepatic cells, parenchymal hemorrhage, perivascular leucocytic infiltration and cellular atrophy in the periphery of the lobules. The glomeruli and the tubules of the kidney were also involved in an inflammatory process. Piras[67] injected subcutaneously daily doses of glycerol ranging from 0.5 to 3 cc. per rabbit for a period of 45 days, killed the animals by bleeding, and studied the histopathological changes in the tissues. The organs primarily affected were the liver, kidneys, intestine and lungs. The liver and kidneys showed marked hyperemia, dilatation of the vessels, hemorrhage, and cloudy swelling. Pulmonary lesions were common to all rabbits, the degree of injury being proportional to the dose injected. There were signs of extensive injury of the mucosa of the intestine, with inflammation, congestion and hemorrhage. According to Tompkins,[77] the repeated injection of sublethal doses of glycerol into guinea pigs caused no permanent pathological changes. Johnson, Carlson and Johnson[29] observed no gross or microscopic tissue changes in rats fed glycerol for a prolonged period. Kobert,[31] however, reported in 1906 that the repeated ingestion of large doses of glycerol leads to a chronic inflammation of the stomach and intestines.

Summary

GLYCEROL is absorbed from the peritoneum, gastro-intestinal tract and subcutaneous tissues; its penetration of the intact skin appears to be negligible.

Toxic doses of glycerol produce a train of characteristic signs and symptoms, and when administered in sufficient quantities, death. The quantity necessary to produce death varies with the mode of administration, being least if given intraperitoneally, intermediate if injected subcutaneously, and largest if given orally. (The lethal dosage by the intravenous route is obscured by the secondary effects of embolism and other direct effects upon the blood). It is not possible to kill rabbits or rats by cutaneous application. Partial starvation decreases the resistance of animals to glycerol poisoning.

The intravenous injection of even small doses is followed by a transient fall in the arterial blood pressure and by an increased rate and magnitude of respiration. Lethal oral doses produce a slowly failing circulation, while lethal intraperitoneal injections produce a marked stimulation of respiration, and finally a sudden drop of the arterial blood pressure. Death is due to the combined effects of failing circulation and respiration..

Glycerol increases the degree of irritability of muscle, causes relaxation of the sphincter of the gall bladder, and appears to increase the force and amplitude of intestinal contractions. It has little or no effect upon the uterus.

The portal of entry, as well as the dose of glycerol, determines the specific effect on the blood picture. Aside from a temporary concentration of the blood, due to the loss of water, the general picture is as follows. Subcutaneous injection produces a decrease in the number of erythrocytes and in the hemoglobin concentration, together with hemoglobinuria. The number of leucocytes fluctuates above and below the normal. Intraperitoneal administration is followed by an increase in the number of leucocytes and by insignificant changes in the number of erythrocytes and in the hemoglobin concentration. Hemoglobinuria may develop in isolated cases. No significant blood change has been reported after oral administration or after cutaneous treatment but intravenous injections are followed by decrease in the erythrocyte count and in the hemoglobin concentration and an increase in leucocytes, after a temporary increase in all the formed elements by reason of the direct effect of glycerol in concentrating the blood. Hemoglobinuria may be produced in isolated cases treated intravenously.

The rate of hemolysis of erythrocytes when whole blood is added to isosmotic glycerol solutions in vitro varies widely for different species of animals. Washed red blood cells are very resistant to hemolysis if placed in a saline-glycerol solution, but they are hemolyzed readily if placed in an aqueous glycerol solution, the rate of hemolysis varying inversely with the glycerol concentration.

The effect of lethal and sublethal doses of glycerol on the body temperature does not appear to be uniform for all species or for different modes of administration. Both pronounced fever and subnormal temperatures have been observed.

Diuresis appears to be more pronounced after oral than after subcutaneous administration, but it is independent of the mode of entry of glycerol into the body. Toxic concentrations in the body, however, inhibit the formation of urine.

A portion of the absorbed glycerol is transformed in the organism into glucose, and thence into glycogen. Glycerol, therefore, is antagonistic to the action of insulin and to the formation of the acetone bodies. Various investigators have employed glycerol as a partial substitute for carbohydrates in the diet with apparently satisfactory results. The total replacement of carbohydrates by glycerol prevents pregnancy.

Glycerol appears to have a protein-sparing action if administered in concentrations well below the toxic level.

The reported effect of this compound in decreasing the respiratory quotient needs verification.

Ingestion of glycerol appears to favor the excretion of uric acid. The mechanism involved is not fully understood.

Glycerol may be excreted as such in the urine if sufficiently large single doses are administered, and also if small amounts are given over a prolonged period.

Glycosuria is not common after absorption of glycerol.

The pathological changes which have been reported in cases of experimental glycerol poisoning are those of acute toxic damage to the liver, kidney and lungs. The gastrointestinal tract may suffer after the administration of large oral doses and the subcutaneous tissues may reveal pronounced local damage at the site of injection.

References:

1. ALESSANDRINI, M. E.: *Ann. chim. applicata* 26:156, 1936.
2. ARNSCHINK, L.: *Ztschr. f. Biol.* 23:413, 1887.
3. BURGE, W. E.: *Am. J. Physiol.* 48:133, 1919.
4. CATILLON, cited by ARNSCHINK, L.: *Ztschr. f. Biol.* 23:413, 1887.
5. CATRON, L. F., and LEWIS, H. B.: *J. Biol. Chem.* 84: 553, 1929.
6. CHAMBERS, W. H., and DEUEL, H. J., JR.: *J. Biol. Chem.* 65:21, 1925.
7. COMPTON, A.: *Lancet* 2:327, 1927.
8. CREMER, M.: *Münch. med. Wochnschr.* 49:944, 1902.
9. CUGUSI, C.: *Arch. farm. sper.* 34:150, 1922.
10. DEICHMANN, W.: To be published.
11. DELAUNAY, H., and ACCOYER, P.: *C. R. Soc. de Biol.* 123:694, 1936.
12. DI FRISCO, A.: *Boll. soc. ital. biol. sper.* 3:299, 1928.
13. DOYON, M., and MOREL, A.: *C. R. Soc. de Biol.* 56: 190, 1904.
14. DUBOIS, C., and COMBEMALE, P.: *C. R. Soc. de Biol.* 89:169, 1923.
15. DUX, P., and LÖW, A.: *Biochem. Ztschr.* 125:222, 1921.
16. FARBER, L., and WYNNE, A. M.: *Biochem. J.* 29:2312, 1935.
17. FERBER, J., and RABINOWITSCH, S.: *Am. J. Med. Sci.* 177:827, 1929.
18. FLURY, F., and ZANGGER, H.: "Lehrbuch der Toxikologie," 1928.
19. HAMMERSTEIN, O.: "Lehrbuch der Physiologischen Chemie," 1914.
20. HANSEN, F., and KAMM, B.: *Biochem. Ztschr.* 173: 327, 1926.
21. HEISE, F. H., and BROWN, L.: Am. Rev. Tuberculosis 6:1084, 1923.
22. HIRSCHFELD, F.: *Z. Klin. Med.* 28:176, 1895.
23. HÖBER, R., HÖBER, J.: *J. Cellular Comp. Physiol.* 10: 401, 1937.
24. HÖCHST, cited by KELLER, W., and DÖLTER, W.: *Beitr. klin. Tuberk,* 69:444, 1928.
25. HOLCK, H. G. O.: *J.A.M.A.* 109:1517, 1937.
26. JACOBS, M. H., and CARSON, S. H.: *Biol. Bull.* 67: 325, 1934.
27. JACOBS, M. H., GLASSMAN, H. N., and PARPART, A. K.: *J. Cellular Comp. Physiol.* 7:197, 1935.
28. JOHNSON, V., and CARLSON, A. J.: *Oil and Soap* 9: 274, 1932.
29. JOHNSON, V., CARLSON, A. J., and JOHNSON, A.: *Am. J. Physiol.* 103:517, 1933.
30. KELLER, W., and DÖLTER, W.: *Beitr. klin. Tuberk.* 69:444, 1928.
31. KOBERT, R.: "Lehrbuch der Intoxikationen," 1906
32. KOIKE, T.: *J. Biochem.* (Japan) 19:111, 1934.
33. KNEIP, J.: *Monatsschr. Kinderheilk.* 64:359, 1935-6.
34. LANG, R. M.: *Biochem. J.* 9:456, 1915.
35. LASZT, L., and SÜLLMANN, H.: *Biochem. Ztschr.* 278:401.
36. LEAKE, J. P. and CORBITT, H. B.: U. S. P. H. S. Hyg. Lab. Bull. 110, 35, 1917.
37. LEDERER, J. A.: *Rev. belge sci. méd.* 8:373, 1936.
38. LESSER, M. A., and MURPHY, J. R.: *Modern Med.* 6: 58, 1938.
39. LEWIN, L.: cited by Hoppe-Seyler in "Physiologische Chemie," 1881.
40. LEWIN, L.: "Gifte und Vergiftungen, Lehrbuch der Toxikologie," 1929.
41. LEWIS, H. B., and CORLEY, R. C.: *J. Biol. Chem.* 55: 373, 1926.
42. LONG, E. S., and VORWALD, A. J.: *Am. Rev. Tuberc.* 22:636, 1930.
43. LUCHSINGER, B.: *Pflüger's Arch.* 11:502, 1875.
44. LÜTHJE, H.: *Deut. Arch. klin. Med.* 80:98, 1904.
45. MCCANN, WM. S., and HANNON, R. R.: *Bull. Johns Hopkins Hosp.* 34:73, 1923.
46. MCLEAN, M. B.: *Monatsschr. Kinderheilk.* 70:220, 1937.
47. MAIGNON, F., and GRANDCLAUDE, C.: *C. R. Soc. de Biol.* 190:899, 1930.
48. MARINE, D., and BAUMANN, E. J.: *Am. J. Physiol.* 81:86, 1927.
49. MIURA, S.: *Biochem. Ztschr.* 36:25, 1911.
50. MUNK: cited by Hoppe-Seyler in "Physiologische Chemie," 1881.
51. NOBLE, E. C., and MACLEOD, J. J. R.: *Am. J. Physiol.* 64:547, 1923.
52. PAL, R. K., and PRASAD, S.: *Indian J. Med. Research* 23:515, 1935.
53. PARNAS, J. K., and WAGNER, R.: *Biochem. Ztschr.* 127:55, 1922.
54. PETZETAKIS, M.: *C. R. Soc. de Biol.* 126:412, 1937.
55. PFEIFFER, C., and ARNOVE, I.: *Proc. Soc. Exper. Biol. and Med.* 37:467, 1937.
56. PFLÜGER, E. F. W.: cited by Catron and Lewis, *J. Biol. Chem.* 84:553, 1929.
57. PIRAS, A.: *Arch. farm. sper.* 40:251, 1925.
58. PLOSZ, P.: *Pflüger's Arch.* 16:153, 1887.
59. POPOFF, M.: *J. physiol. path. gén.* 21:482, 1923.
60. QUICK, A. J.: *J. Biol. Chem.* 98:157, 1932.
61. REACH, F.: *Wien. Med. Wochnschr.* 76:369, 1926.
62. REEVES, H. G., and HEWITT, J. A.: *Proc. Physiol. Soc., J. of Physiol.* 61:35, 1926.
63. REID, C.: *J. Physiol.* 84:40, 1935 and 87:113, 1936.
64. ROSENFELD, F.: *Klin. Wochnschr.* 3:1908, 1924.
65. SALOMON: cited by Hoppe-Seyler in "Physiologische Chemie," 1881.
66. SANTESSON, C. G.: *Skandinav. Arch. Physiol.* 14:1, 1903.
67. SATTA, G.: *Beitr. chem. Physiol. und Path.* 6.376, 1905.
68. SCHELLENBERG: cited by Kobert, "Lehrbuch der Intoxikationen," 1906.
69. SCHÜBEL, K.: *Sitzungsber. der Physikalisch-medizinschen Sozietät zu Erlangen* 68:263, 1936.
70. SIMON, I.: *Arch. farm. sper.* 20:120, 1915.
71. SIMON, I.: *Arch. Sci. Biol.*, 1:225, 1920.
72. SIMON, I.: *Arch. farm. sper.* 30:53, 77, 81, 102, 1920; *Gazz. ospedali clin.* 41:76, 1920.
73. SMITH, M. L.: *Brit. J. Exptl. Path.* 18:265, 1937.
74. STRACK, E.: *Ber. über die Ges. Physiologie* 61:376. 1931.
75. SUGIMOTO, K.: *Arb. dritt. Abt. anat. Inst. kaiserl. Univ. Kyoto, Ser. D.*, No. 5, 154, 1935.
76. TASHIRO, S., and OLIVER, S.: *Med. Bull. University of Cincinnati* 6:40, 1931.
77. TOMPKINS, E. H.: *Am. Rev. Tuberc.* 20:908, 1929.
78. TRABUCCHI, E.: *Boll. soc. ital. biol. sper.* 7:916, 1932.
79. TSCHIRWINSKY: cited by Hoppe-Seyler in "Physiologische Chemie," 1881.
80. USTIMOWITSCH, C.: *Pflüger's Arch.* 13:453, 1876.
81. UTZ: *Deut. Parfüm. Ztg.* 7: 105, 1921.
82. VERZÁR, F., and PETER, F.: *Arch. ges. Physiol.* 207: 192, 1925.
83. VERZÁR, F., and LASZT, L.: *Biochem. Ztschr.* 270:24, 1934.
84. VOEGTLIN, C., THOMPSON, J. W., and DUNN, S. M.: *J. Biol. Chem.* 64:639, 1925.
85. VOEGTLIN, C., DUNN, E. R., and THOMPSON, J. W., *J. Pharmacol. and Exp. Ther.* 25:168, 1925.
86. VON EULER, H., and ERICKSON, E.: *Z. physiol. Chem.* 146:241, 1925.
87. WEISS: *Wien. Acad. Sitzungsber.* 67: Jan. 2, 1873, cited by HOPPE-SEYLER in "Physiologische Chemie," 1881.
88. WOOLF, M. S.: *Med. World* 56:303, 1938.
89. YAGI, K.: *Folia Endocrinal, Japon.* 12:19, 1936.

Toxic Limits

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THE foundation of modern science and modern technique is the process of weighing, measuring and counting. The step from the empirical state to modern science, from skilled handiwork to mechanical performance was possible only after methods for specific weighing and measuring had been found. Exact examinations of air and its contaminants in factories were great rarities even 20 and 15 years ago; indeed determinations of dust concentrations were the only such measurements made to any appreciable extent and these were done in English speaking countries alone. No other instruments were available for investigations in factories except those for determining the dust contents. (In the United States, the sugar-tube, Palmer apparatus, Greenburg-Smith impinger; in England, Owens dust counter; in South Africa, Kotzé konimeter.) The methods and instruments used in laboratories have also been used in factories, instruments difficult to handle and transport, often not accurate. All this is different today.

We now have various instruments suitable for use in factories, although the truly exact instrument and the precise method is still lacking for certain purposes. On the contrary we even suffer from too many offers of instruments made by firms and scientists. Their only small deviation from already existing instruments makes it more difficult to compare the results, since the new instruments often do not guarantee any greater accuracy.

R. R. Sayers[1] published in 1927 data about the most important poisons, briefly summarizing them. As far as I know, Zangger[2] in 1928 was the first author to compile a table "about the effect of irritant and poisonous gases and vapors." For many gases he specified the exact concentration in milligrams per liter which would kill immediately or be fatal after ½-1 hour. He defined which concentration may be borne with large, small or no damaging effect for a period of time. The compilation is supported for the largest part by animal experiments, made by K. B. Lehmann and his collaborators, Zangger, U. S. Bureau of Mines, Haldane, Henderson and Haggard. Experiments on human beings (experiments on the author himself) are rarely referred to. An extension and completion of this table may be found in the book, Noxious Gases by Flury and Zernik.[3]

The table, "Maximum Allowable Concentrations," compiled by Bowditch[4,5] was especially meritorious as it included tabulation of regulations of other governmental authorities in addition to those suggested for Massachusetts. These had been referred for criticism to more than a score of the leading authorities in this country and abroad prior to their promulgation. This table has been revised and extended by himself, C. K. Drinker, P. Drinker, H. H. Haggard and A. Hamilton[6]. By formulating the problem into "*allowable concentrations*" it has been taken out of the field of theoretical research and *transferred to the practical industrial hygiene.* But the ready availability of apparatus easy to handle and of tables of toxic limits established by well known scientists to which the results can be referred for interpretation may lead to the undesirable situation that men not well trained in industrial hygiene will underestimate the difficulties of obtaining truly representative results. In addition there is the danger that they will employ these results beyond their limits of usefulness and so draw unjustifiable conclusions.

Therefore the *value of the limits,* the *practical purpose* and the *limitations* of their use may be discussed in the following lines.

A SHARP distinction must be drawn between acute and chronic action which must be applied especially to those materials which produce acute and chronic occupational poisoning (benzol, toluene, xylene, carbon disulfide, trichlorethylene, aniline, ozone, etc.). The "allowable concentration" is much higher where there is danger of acute poisoning than under conditions where there is continuous inhalation for a long time. It is evident that it would be out of place to demand the same limiting value of contamination where the workers are only occasionally exposed to the danger of acute poisoning (transferring benzol, trichlorethylene, carbon bisulfide, etc., or similar intermittent work performed at extended intervals) as in places where there is danger of continuous inhalation for a period of weeks or months.

The Massachusetts publication quoted above seems to give the "allowable concentrations" for those actions which are most important in industrial hygiene: the chronic influence of benzol and its homologues, the acute poisoning by CO. Although the expert knows or is able to find out for which situation the given value is applicable, it would be expedient *to specify in the table the limits for acute and those for chronic poisonings.* If that is not possible or not necessary for some substances, it should be stated clearly whether the quoted value refers to acute or chronic action.

Of course, the conceptions of "acute" and "chronic" are not sharply differentiated. But generally we may call poisonings and damages acute when they can take place within a working day; and we may call them chronic when they need a longer time to develop — usually weeks or even years.

A specification of the concentration fatal in a half hour or less, although scientifically interesting, is of little value for practical industrial hygiene as pointed out below.

As examples of the damages which arise after harmful action of years or decades may be mentioned silicosis, bladder cancer of aniline workers, the symptoms of chronic alcoholism, certain damages by x-rays and radium, some serious forms of carbon bisulfide poisonings, mercury shakes, the changes of the vessels and as a rule the pareses as a result of lead poisoning.

But if a man working with lead for many years

falls ill with lead colic, i.e., the subacute form of lead poisoning, it is correct to suspect that he has recently absorbed an exceptionally large amount. The same cause — a larger amount of absorbed poison — may also be considered in case a man working with mercury for many years acquires gingivitis and diarrhea; and if serious blood change in a man working many years with benzol is not started by infectious disease, it is possible that it was caused by a larger recent absorption of benzol.

Many animal experiments are at hand concerning concentration and duration of air contaminations which cause temporary or lasting injury — but their application to man is either not feasible or to be done only very cautiously.

There are important differences between the different species of animals. The fatal concentration of carbon monoxide poisoning at 32° C. is above 0.12% by volume for the rat; above 0.25%, for the guinea pig and above 0.38% for the rabbit.

Flury and Zernik[3] tell us that cats, mice, rats are very sensitive to phosgene; dogs are less sensitive, rabbit still less. Horses are less sensitive than human beings. When the driver died in gas attacks during the World War, the horses sometimes showed only slight symptoms of poisoning.

Our conclusions therefore on acute poisonings have to be based preferably on the experiences we have had with man. For chronic poisoning and damages the animal experiments fail entirely to be useful for our purpose because it is impossible to determine the comparability of the time required for injury to develop in animal and in man.

A study of conditions which may produce chronic poisonings presents a number of difficulties. The contamination of the air can be determined during the whole working shift very well, but is it impossible to ascertain the circumstances under which the injurious material was absorbed during months and years gone by.

If it is admitted that the conditions affecting industrial health have improved in the course of years — which is true in general, but not in every single case — or that the working time is shortened, then the amount of injurious material absorbed in a working day was larger in former times than it is now. But it may also be that the damaging material is not used such a long time, as the case history may tell us, or that its concentration has been increased recently; such as unnoticed substitution of benzol for benzine or a benzine-benzol mixture, or substitution of lead for color containing little or no lead.

Therefore it must be remembered that all results are approximate values only. But the most important materials, especially in regard to their chronic poisonings (benzol, carbon disulfide, lead) have been studied with such thoroughness and skill by our best industrial hygienists that the obtained figures are actually practicable as limits.

But the observations about some other substances (cadmium, chlorine (chronic), dichlorethylene and many others) are too limited in number and not clear and reliable enough to make even partly safe conclusions. If figures about such substances are included in the list at all *a mark of interrogation has to be added.*

The limits are approximate, not only on account of the difficulty of most of the observations, but also on account of differences in sensitivity of individual persons and on account of different amounts of the contaminated air absorbed by the worker under different circumstances. For instance, the worker when working hard inhales much more of the contaminated air (up to 50-60 liters per minute) than when doing light work (8-10 liters per minute).

But these lists of toxic limits give the practical industrial hygienist essential data for his work; they save laborious studies of literature and give him the results obtained by those carrying on research and basic investigation. *Therefore we have to be thankful for the compilations of the limits by their authors.*

How are the "limits" to be utilized? For which purposes may they be used? What is their immediate practical advantage and when may they be applied?

FIRST of all: The limits strongly support the industrial hygienist in arriving at an opinion as to whether the exposure is or is not excessive, and, if so, in convincing incredulous employers and engineers (under certain circumstances) that the contaminated air in their rooms is injurious even though the contamination cannot be readily seen or smelled. The data on the exposures, if properly substantiated, act as impartial arbitrators between the man recommending control measures and the man persisting in the present situation.

The limits are useful in construction and testing exhaust systems. Naturally you will try to remove every contamination of the air, because only that gives complete security. If that is not possible, you must insist that the ventilation has at least such an effect as to reduce the exposure to less than the "allowable concentration" in the breathing zone. If that is impossible, you have to try to bring about hygienic conditions by changing the operation or by abandoning the use of the poisonous substance.

I might indicate that exhaust ventilation seems to be considered too much as the principal remedy nowadays, as the respirator was considered some years ago though with much less foundation. Other procedures mentioned above are sometimes forgotten today, although they have attained great success in industrial hygiene.

If the limits are used, it must be definitely ascertained that *the evaluation of the contamination in the air is reliable.*

Because the testing devices are reasonably priced, easy to handle and because the methods of examination in laboratories are frequently simplified, there is (as remarked previously) the danger of unqualified men using them. Therefore the following has to be stressed:

Serious acute poisonings, especially fatal ones, arise through unforeseen accidents — as leaking of vessels, pipe lines, or by unexpected formation of gases in larger amounts or by other abnormal

events. Also, by exceptional atmospheric conditions where the removal of gases is not effected by strong mechanically driven exhaust systems.

A locksmith was found dead beside his forge fire where he had been seen working 20 minutes before. As an exhaust pipe had been installed in this place and the man had worked here for many years, the technician thought a CO poisoning impossible—the blood of the dead man however was found to be saturated with CO. Abnormal cold and severe storms had interfered with the natural up-draft existing at other times. I have seen CO poisoning with unconsciousness in some working places of a large plant in presence of such abnormal weather; the workers had worked in these places without disturbance of health for months.

I have seen poisonings by arsine as a result of using too strong an acid so that the solution was not neutralized; as a result of too much zinc powder being added; and as a result of an exhaust pipe being obstructed by the formation of foam.

Such circumstances caused by abnormal accidental events cannot be investigated by air examination because we do not know all contributing factors and therefore we are not able to reproduce these circumstances (to say nothing of the danger to the investigator). Therefore, as mentioned above, data about the deadly concentration would be of little practical value.

In all other circumstances it is self evident that *only numerous samples* of air give a true picture of the existing conditions, if taken *at different times* and during different working processes and in the exact working place at the *breathing level* of the worker. Samples taken off-hand are without any value.

THE investigator has to be certain that the working processes during the time of examination are the same as at other times. The investigator can be misled intentionally or unintentionally. The occurrence of illness should of course induce the improvement of the working conditions. When we investigate we have to know if such changes have taken place or not. It is sometimes difficult to find that out.

Another difficulty which may be overcome only by patience is the fact that all persons concerned — even involuntarily — work more "according to prescription" if observers and supervisors are present.

In addition it must be taken into consideration that little variations — produced intentionally or not — are able to change the whole picture; small changes hardly detectable in the process produce considerable differences in the amount of contamination in the air; season (open or closed windows), and weather also influence the picture.

An electrolytic nickel plating bath delivers more hydrocyanic acid gas, a chrome plating bath more chromic acid mist, when the current is heavier or the treated objects larger. The amount of lead fumes depends, among other factors, on the temperature of the lead bath, the zinc oxide fumes on the temperature of the molten alloy. More vapor escapes in an apparatus for degreasing by trichlorethylene if the trichlorethylene is heated more and if it is not cooled before emptying. The quantity of escaping vapors changes in the usual degreasing apparatus with the temperature of the water used in the cooling coil, with the size of the objects and their number and with the frequency and speed with which they are taken out.

Ball mills pulverizing rock have often been submitted to my inspection and I was shown they were working without escape of dust, — it was soon after loading large rock. But half an hour later, when the material has been reduced to fine powder, much dust was escaping into the breathing zone.

To give some examples of numerical differences: Dust concentrations found in my investigations in grinding shops[7] in the summer by the Owens dust counter have averaged between 600 and 1500 particles per cm^3 in the same room, at the same speed of rotation of the sandstone wheels but grinding different kinds of knives. In winter, when the windows were closed, the figures ran up to 3700 at the breathing level of the worker. In the air of the room in general the dust figures averaged to 560 in summertime, 3300 in winter. Bowditch and Elkins[8] found in the coating room of an artificial leather factory on different days in March 130-200 parts per million of benzol; concentrations of 300-1300 ppm of naphtha vapor were detected during the work done by one worker in a factory using rubber cement. Greenburg and corroborators found in a rotogravure printing plant 50-1060 ppm of benzol in different parts of the press room.

I think it is not necessary to stress that all the difficulties mentioned above have to be regarded especially if there is a compensation case, or if there is a question of negligence.

Summarizing: A well-trained industrial hygienist only is able to make investigations in industrial hygiene and especially for answering the question, if, when or how often limits are transgressed; and besides he can answer only after a long-lasting and exact examination.

It should never be forgotten, that all our limits have their origin from health examination of workers and that only from comparison between the results of these physical examinations and the content of contamination in the air do the limits result. All the mentioned uncertainties and difficulties can be avoided in many cases if we refer to this origin. If there is a danger of chronic poisoning the thorough investigation and examination of the workers especially for early symptoms give us a sure answer in cases where the time is long enough for acquiring symptoms of chronic poisoning.

We may also see if the contamination is able to produce acute poisoning by examining the workers at the end of the daily working time.

A special consideration must be given to the question if and how far the results of air examinations and their relation to the limits are able to contribute in determining the occurrence of an *occupational disease.*

The question of whether there is an occupational disease presents itself as a medical question. A physician only is able to answer it after considering all the clinical symptoms and after a thorough medical examination executed with all necessary aids.

The clinical pictures (and the pathological one in the autopsy) of the more frequent occupational diseases (chronic poisonings by lead, mercury, benzol, silicosis, to some extent carbon disulfide, and certain acute poisonings as CO) have been studied so carefully and are so well established that the diagnosis can be made with greatest certainty — by a physician experienced in this field as is the case with every other medical diagnosis.

We have mentioned above the difficulties and uncertainties of air examinations. We cannot guarantee that the air contamination during the investigation was the same as in the time before the poisoning occurred. Therefore negative findings in air contaminations or findings below the limits are never able to shake such a positive medical diagnosis though under certain circumstances it is possible that a former occupation may have been responsible for the disease. Positive findings on the other hand are able to support it. Furthermore if we have a clinical picture that according to medical opinion does not correspond with the well known picture of this poisoning nor with signs of its rare varieties and therefore the physician denies an occupational disease, then the findings of air contamination above the limits is no proof of a causal connection between the illness and the contamination; the illness may have originated entirely independently of the contamination because of an internal or another external cause.

But there is another method which gives us an insight into the circumstances under which the ill man worked prior to his disability and which should be practiced in chronic poisonings if it can be done shortly after the beginning of his illness: The physical examination of the fellow-workers (still working, disabled and dismissed). If the symptoms of the same illness are found, it confirms our diagnosis of the case in question. Negative findings are of small value, because the sick man may have been more exposed to the damaging substance or may be more sensitive.

In acute poisonings the examination of the fellow-workers should be made at the end of the shift.

There is however, a long list of less explored substances (most at present rarely used), the clinical pictures of which are not clearly worked out as yet — nor are their toxic limits. We are able to conclude that there is a causal connection if certain substances are found in the air and contemporarily symptoms of illness determined in a worker and if these symptoms agree with those mentioned in the literature as a consequence of this poison or if similar pictures are to be seen among the fellow-workers.

But cases occur when a positive medical diagnosis alone is not sufficient. For compensation cases and for prophylaxis it may be of greatest importance to know through which kind of work the illness is acquired.

If the examination of the air fails to give exact proof, then all chemical and other processes should be subjected to the opinion of experienced experts in technology, chemistry and industrial hygiene. In such cases all the impurities possibly present in the substances used are to be considered.

I wrote above "experienced physicians." The universities (medical schools) should give better instructions to students of medicine in industrial hygiene and in occupational diseases. Especially in the latter field, there should be established short courses for physicians also. The legislation, the industrial commissions, the insurance companies, the employers and the employees should take advantage first of all of such trained physicians and thus give them occasion to acquire still greater experience.

Summary

TO DEFINE toxic limits is of the greatest scientific and of the greatest practical value.

2. It should be made evident whether the toxic limit applies to acute or chronic poisoning, if it is well founded or doubtful.

3. The limits are valuable help in showing the necessity of prophylactic measures in a plant for the construction of new and for testing of existing installations. But the examinations should be made very carefully and by experienced industrial hygienists. In determining the severity of exposures resulting from existing installations, the medical examination of workers often gives a better insight.

4. It is the field of medical diagnosis to ascertain the presence or absence of an occupational disease. This diagnosis made by an expert physician cannot be shaken by a contrary result of air examination, but if this result is certainly representative of the worker's exposure, it may point to the desirability of further investigations.

References:

1. SAYERS, R. R.: Toxicology of gases and vapors. International Critical Tables of Numerical Data, National Research Council of the U. S. Vol. II. p. 318-321. McGraw-Hill Book Co., Inc., New York, 1927.

2. ZANGGER, H.: Flury-Zangger Lehrbuch der Toxikologie. p. 256. Julius Springer, Berlin, 1928.

3. FLURY, F., and ZERNIK, F.: Schädliche Gase. p. 453. Julius Springer, Berlin, 1931.

4. BOWDITCH, M.: Maximum allowable concentration. Div. of Occ. Hygiene, Mass. Dept. of Labor & Industries, Boston, February, 1937.

5. ELKINS, H. B.: Toxic fumes in Massachusetts industries. *Indust. Med.* 8, 426-432 (October, 1939).

6. BOWDITCH, M., DRINKER, C. K., DRINKER, P., HAGGARD, H. H., HAMILTON, A.: Code for safe concentrations of certain common toxic substances used in industry. *J. Ind. Hyg. & Tox.* 22, 251, (1940).

7. TELEKY, L., LOCHTKEMPER, I., ROSENTHAL-DEUSSEN, E., DERDACH. Staubgefährdung und Staubschädigungen der Metallschleifer. R. Hobbing, Berlin, 1928.

8. BOWDITCH, M., and ELKINS, H. B.: Chronic exposure to benzene (benzol). I. The industrial aspects. *J. Ind. Hyg. & Tox.*, 21, 321-330 (1939).

9. GREENBURG, L., MAYERS, M. R., GOLDWATER, L., and SMITH, A. R.: Benzene (benzol) poisoning in the rotogravure printing industry in New York City. *J. Ind. Hyg. & Tox.*, 21, 395-420 (1939).

National Conference

—of Governmental Industrial Hygienists—

THE complete gamut of industrial hygiene is covered in the papers and committee reports of the Third Annual Meeting of the National Conference of Governmental Industrial Hygienists held at Bethesda, Maryland, April 30, May 1, 2, 1940. The Transactions have been published and include, as a valuable entity in itself, the discussions on the subjects presented. Copies of these Transactions are available on application to Division of Industrial Hygiene, National Institute of Health, Bethesda, Maryland.

The titles of the technical papers and reports of committees are given below.

April 30, 1940—Morning Session

OPENING Remarks—DR. R. R. SAYERS, Director, United States Bureau of Mines.

Address of Welcome—DR. THOMAS PARRAN, Surgeon-General, United States Public Health Service.

April 30, 1940—Afternoon Session

SYMPOSIUM on Interdepartmental Relationships:

"The Viewpoint of a State Health Department" — LESTER A. ROUND, Director of Health, Rhode Island.

"The Viewpoint of a State Industrial Commission"—THURSTON A. WILSON, Chairman, North Carolina Industrial Commission.

"The Physician and the Industrial Hygiene Services"—DR. C. M. PETERSON, Secretary, Council on Industrial Health of the American Medical Association.

"Relations of Official Industrial Hygiene Services with Industry"—DR. C. D. SELBY, Medical Consultant, General Motors Corporation.

May 1, 1940—Morning Session

MEDICAL SECTION: "A Physical Examination Program for Industrial Workers"—DR. PAUL A. BREHM, Supervisor, Industrial Hygiene Unit, Wisconsin.

"The Lead Hazard in the Storage Battery Industry"—DR. CARL A. NAU, Director, Division of Industrial Hygiene, Texas.

"Industrial Health and the Industrial Medical Program" —DR. KENNETH E. MARKUSON, Director, Bureau of Industrial Hygiene, Michigan.

"Syphilis Case Finding and Case Holding in Industrial Workers"—DR. ALBERT E. RUSSELL, Surgeon in Charge, Syphilis Control in Industry, U. S. Public Health Service, Chicago.

NON-MEDICAL SECTION: "Applied Principles of Exhaust Ventilation"—WILLIAM N. WITHERIDGE, Ventilation Engineer, Bureau of Industrial Hygiene, Detroit, Michigan.

"Problems in Industrial Hygiene Air Sampling"—DR. W. G. FREDRICK, Chief Chemist, Bureau of Industrial Hygiene, Detroit, Michigan.

"Methods of Analysis of Air-Borne Contaminants"—ALFRED N. SETTERLIND, Chief Chemist, Division of Industrial Hygiene, Illinois.

May 1, 1940—Afternoon Session

INTRODUCTORY Remarks"—DR. P. A. NEAL, Acting Chief, Division of Industrial Hygiene, U. S. Public Health Service.

"Recent developments in Environmental Studies in Industry"—R. T. PAGE, Associate Public Health Engineer, U. S. Public Health Service.

"Remarks on the Research Laboratories of the Division of Industrial Hygiene"—DR. P. A. NEAL, Acting Chief, Division of Industrial Hygiene, U. S. Public Health Service.

"Recent Analytical Problems in Evaluating the Industrial Environment"—F. H. GOLDMAN, Associate Chemist, U. S. Public Health Service.

"Pneumoconiosis Due to Certain Silicates"—W. C. DREESSEN, Passed Assistant Surgeon, U. S. Public Health Service.

"Protective Ointment for the Prevention of Poison Ivy Dermatitis"—LOUIS SCHWARTZ, L. H. WARREN, and F. H. GOLDMAN, U. S. Public Health Service. (Presented by Dr. Schwartz).

"The Relative Toxicity of Lead and Some of Its Common Compounds"—LAWRENCE T. FAIRHALL, Principal Industrial Toxicologist, U. S. Public Health Service.

"Recent Studies and Theories on the Mechanism of the Action of Carbon Monoxide Poisoning"—W. F. VON OETTINGEN, Principal Industrial Toxicologist, U. S. Public Health Service.

"Fatigue and Hours of Service of Interstate Truck Drivers"—R. H. FLINN, Passed Assistant Surgeon, U. S. Public Health Service.

May 2, 1940—Morning Session

REPORT of Committee to Study Methods of Appraisal of Industrial Hygiene Problems in a Locality, 1939-1940"—DR. CRIT PHARRIS, Chairman.

"Report of Committee on Technical Standards"—THEODORE HATCH, Chairman.

"Report of Committee on Industrial Hygiene Education"—DR. CARL A. NAU, Chairman.

"Report of Committee to Study Methods for Securing Effective and Uniform Reporting of Occupational Diseases and Other Illnesses Among Workers"—DR. J. M. MCDONALD, Chairman.

"Report of Committee on Administrative Development of Industrial Hygiene Activities in the State Through Local Departments of Health—DR. K. F. MARKUSON, Chairman.

"Report of Committee on Administrative and Technical Relationships"—DR. ALBERT S. GRAY, Chairman.

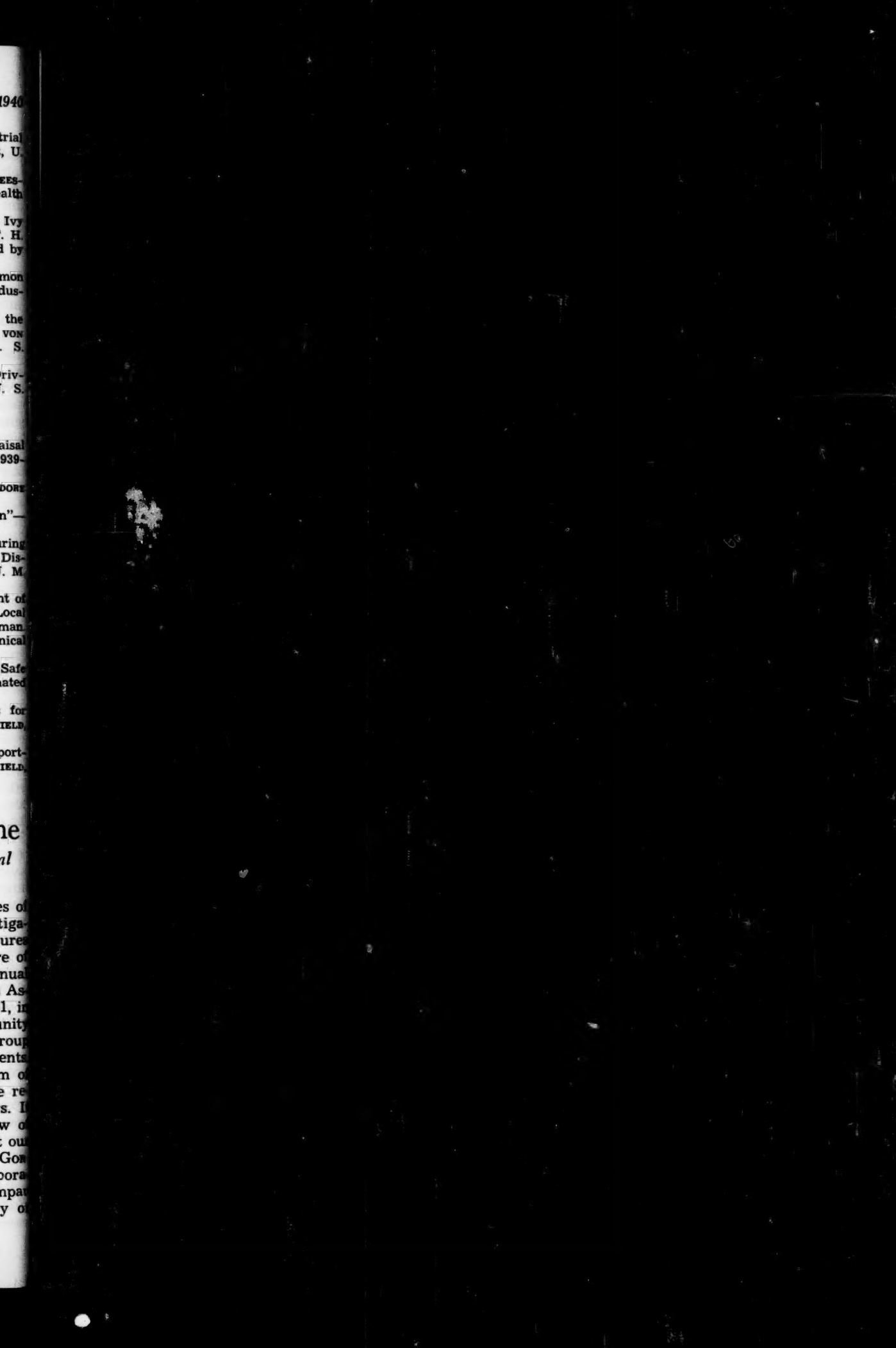
"Proposed Recommendations for the Installation and Safe Operation of Dry Cleaning Systems Using Chlorinated Solvents"—

"Report of Committee on Minimum Qualifications for Industrial Hygiene Personnel" — J. J. BLOOMFIELD, Chairman.

"Report of Committee on Appraisal and Uniform Reporting of Industrial Hygiene Activities"—J. J. BLOOMFIELD, Chairman.

Data on Industrial Hygiene

—First Call for Papers for the Annual Meeting—

ORIGINAL research in the various phases of industrial hygiene and results of investigations of occupational disease exposures which have not yet been brought to light are of value to others working in this field. The Annual Meeting of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION—to be held the week of May 5, 1941, in Pittsburgh, Pennsylvania—affords an opportunity to present papers on these subjects before a group which is most concerned with such developments.

In an effort to provide a balanced program of high quality papers, the Program Committee requests the cooperation of Association members. If you are at present engaged in work or know of work being done which should be reported at our meeting, will you communicate at once with GORDON C. HARROLD, Ph.D., Industrial Hygiene Laboratory, Chrysler Corporation, 7900 Joseph Campau Avenue, Detroit, Michigan, who is Secretary of the Association.